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SPACE TECHNOLOGY, ITS INFLUENCE ON SCIENCE AND ENGINEERING

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16. Abstract

Three basic directions in the development of space technology are defined. These directions are the scientific tests, technology for making repairs in space, and production of various materials and components in space. Practical examples of these directions are discussed.

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The conquest of space by mankind has given a powerful impetus to the development of various branches of science and engineering, including the manufacture and treatment of metals used in the construction of space vehicles. Today no one doubts that in the very near future it will be necessary to perform directly in space various technological operations connected with the heating and fusing of metals. Work of this sort is carried out both in the Soviet Union and in the United States of America. As is well known, on October 16, 1969 in the USSR on the space vehicle "Soyuz-6", the first experiment involving the welding and cutting of metals was performed, initiating space technology. In the summer of 1973, an experiment on fusing and welding of metals was conducted by the crew of the American orbiting laboratory "Sky Lab". /34*

What explains the very keen interest of engineers in the conduct of experiments in space with molten metals? In our opinion this is due first of all to the fact that the conditions prevailing in space cannot be reproduced on Earth. On the one hand, this unquestionably complicates the technology, and on the other, it may open up prospects at present unknown to science and engineering. At the present time, specialists are

* Numbers in margin indicate pagination in original foreign text.

faced with the problem of studying carefully the behavior of molten metal in space, and working out the basic ways of treating it under these conditions.

As a minimum, one can now characterize three directions in the development of space technology.

First of all there is the conduct of a complex of scientific tests. In particular, this involves a careful study of the behavior of a liquid metal, so that in the future one may actively use the data collected. Not only single phase systems (liquid only) must be studied, but also multiphase systems, i.e., liquids containing solid and gaseous inclusions. It is necessary to investigate the principles of cooling and crystallization of molten metal (in the free state and with forced heat extraction along one or several axes), the bases of phase separations, the effect of the forces of surface tension and wettability with various combinations of phases and materials, and a series of other questions. For all of these things, there is a need for special testing equipment.

The second direction involves the creation of the technology and equipment for making repairs and installations in space. The experience of recent years has shown that space vehicles can be subject to major repairs. In such an event, it may be necessary to separate metals and parts by cutting, or to join them by welding, soldering or cementing. This kind of work is required during the installation in orbit of orbiting stations and other objects equipped from units which will be taken out into the assembly zone separately. In a number of cases it will be necessary to seal hermetically openings, gaps or joints. For such work, special equipment and special technology for repair, assemblage and hermetic sealing is necessary. Some of the prime questions concern the study of the ergonomic and physiological capacities of the cosmonaut operators and the creation of various auxiliary devices facilitating the completion of tasks and ensuring the safety of personnel.

The third direction concerns the production of various materials and components. Scientific-technological investigations allow one, obviously, to envision a series of materials and components whose prospective production in orbiting stations or laboratories becomes possible and advisable. In this connection it is even now possible to mention various composite materials based on light alloys reinforced by high strength filaments or threads; monocrystals for the needs of the radio-electronic industry; special castings whose properties will differ significantly from those produced under conditions on Earth.

As is evident, the most important problem is the development and testing of equipment and devices which are specially designed for scientific research and technological work in space. Participating in its solution are collectives of the Academies of Science of the USSR and the Ukranian SSR. The experience accumulated by the Ye. O. Paton Institute of Electro-Welding of the Academy of Sciences of the Ukranian SSR during more than eight years makes it possible to determine the basic requirements for such equipment. Foremost is functional reliability. Closely connected with this is ensuring complete safety when working with technological equipment designed for space conditions. This is especially important when processing equipment to be controlled directly by cosmonauts.

One of the basic requirements is small weight and small size and negligible energy capacity of equipment. This is achieved through the use of highly efficient heat sources, such as an electron beam or a forced countergyrational high temperature arc of low pressure. Efficient construction and use of special materials can also reduce to a minimum the weight and size of the devices.

It is very important that units for working in space be as multipurpose as possible. There it is not advisable to use different devices for each operation or series of single type operations. One should endeavor to make it possible for one set-up to be used for all work required on board a space vehicle or outside it by re-equipping or replacing individual parts.

All diverse devices for technological work in space can be divided into the following basic categories: completely automated units with programmed control (they are used when the region and character of the work is already known and has been established on Earth), automated units with remote or programmed control, portable units with manual control, manual technological tools. In addition, various combinations of the stated categories of equipment are possible.

It is common knowledge that the performance of any experiment in space entails great expense. Hence it is considered advisable to carry out all preliminary developmental work on Earth, using various simulations of conditions in space. The equipment for investigating technological processes in space developed by the Institute of Electro-Welding was subjected to just such a cycle of preliminary tests.

Tests on the ground made on special experimental stands have /35
not yielded any new information in comparison with that previously obtained in a series of welding and metallurgical vacuum devices. This is related to the fact that the speed of evacuation of the gases from the chambers of the stands was not very great and did not completely simulate the conditions in open space, despite the quite high vacuum (10^{-6} mm Hg). From this point of view, the tests

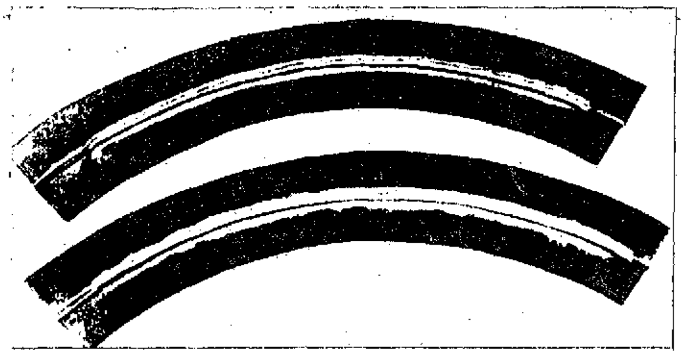

Figure 1. Samples of welded joints produced in space on board a flying laboratory.

Figure 2. The "Vulcan" device.

conducted in vacuum chambers of greater capacity (up to 30 m) with special vacuum pumps proved to be more successful.

It was possible to obtain much richer material in the course of experiments in a flying laboratory in a reequipped airplane containing these stands. Analysis of the results of extensive and varied experiments allow one to establish the most characteristic features of the tested methods of heating and welding of materials (electron beam, plasma, arc, heliowelding, etc.) during work in space. These features, which on the whole are common to all methods, reduce to the following. When molten metal is in space for a brief time, e.g., in a flying laboratory, the study of the fusion and free crystallization of metals turns out to be unusually complicated. Under these conditions and in a vacuum it is practically impossible to crystallize metal of greater extent than 10 - 15 mm. Nevertheless, during heating in a permanent mold, it was observed that molten metal flows more easily along the walls of the mold in space if good wetting has occurred. If, on the contrary, the material of the mold has not been wetted by the molten metal, then the latter is easily localized in drops and escapes from the mold, probably under the influence of the electrostatic field, the magnitude of which is significant during electron beam welding.

On welded joints the identity of the amount of melting and the form of the weld was established under circumstances involving the force of gravity and in space (Figure 1). On samples made of certain aluminum alloys obtained in space, several large porosities were observed. This may be explained by the deterioration of the separation of the gaseous and liquid phases in the absence of the force of gravity. Quite significant changes were also noticed in the microstructure of metals remelted in space.

The process of electron beam cutting in space did not lead to special complications. At the moment of weightlessness, the molten metal did not move away from the cutting chamber, but crystallized along the edges either in the form of a continuous shaft or in the form of drops.

Thus, these experiments confirm fully the ability to carry out welding and cutting of metals under the conditions of brief weightlessness.

Of particular interest are the results of an investigation of the process of electric arc welding with a molten electrode. In this case, the drops of electrode metal turned out to be several times larger than on Earth. The production of drops of such a size may hold great possibilities when melting metal. At the same time methods were found for controlling melting and the size of drops in space which justify one in assuming that welding with a molten electrode is one of the most promising methods for space.

On the whole, investigations show that simulated space conditions in special vacuum stands installed in a flying laboratory are very efficient in studying various technological processes and in developing equipment. This method is especially effective in case there is direct, active human participation in the experiments undertaken. In this connection a special experimental stand was developed which, apart from the possibilities described, allows one to simulate the work of a human being in a spacesuit while he is performing various technological operations.

The final stage of the investigations was a technological experiment involving welding and cutting of metals under conditions prevailing in space in the vicinity of the Earth. For the purpose of this experiment, a special "Vulcan" device (Figure 2) was developed in the Institute of Electro-Welding. This device is a self-contained composite apparatus which makes it possible to perform welding by several methods — electron beam, compressed arc, and molten electrode.

In accordance with the general program of space investigations, this first experiment with welding and cutting of metals in space in the "Vulcan" device was conducted in the vehicle "Soyuz-6". The results of the experiment were published in the Soviet and the foreign press. In brief, one may observe that the process of melting and cutting metals was carried out in a stable fashion, so that the essential conditions for forming a welded joint or for cutting were fulfilled.

The small size welding apparatus provided in the composite "Vulcan" device displayed adequate reliability and efficiency in space. The principal solutions obtained during its construction, and the data obtained during the experiment will serve as the basis for the construction of special welding devices for carrying out technological operations in space.

Thus the conquest of space, giving impetus to new investigations in the areas of welding and metallurgy, has forced engineers and experimenters to engage in the development of new, highly efficient technological processes and reliable, small size equipment, the first tests of which were successfully accomplished both by us and the USA.

Obviously, in the near future one should expect new experiments in metallurgy, welding and cutting, which are of specific importance both for the flights of space vehicles, as well as for obtaining new material.

Consequently, one may assume that the creation of the technology and the equipment for thermal processing of metals in /36 space will exert a great influence on the construction of future space vehicles, especially those which operate for a long time. In the construction of such vehicles, plans should be provided for routine and emergency repairs of individual units or blocks related to heating, melting, or sputtering of metals.

However, the importance of such investigations does not reside solely in these matters. In fact, their results are used in fields related to the study of space. Thus during the development of the electron beam apparatus for work in space, new engineering solutions were found for the construction of high voltage units and electron accelerators; these solutions form the basis for the construction of powerful, small electron accelerators intended for probing the plasma in the vicinity of the Earth.

The new methods for welding, cutting and soldering metals applied in the course of the investigations for the development of space technology have found application in metal-working industries. To begin with, mention should be made of the low-pressure compressed arc and of arc welding with a molten electrode in a high vacuum. In serial welding devices, a number of new materials are now used which are employed in building space vehicles.

Qualities for hot working of metals (high reliability, safety, small size, weight and energy requirements, the ability to work in a high vacuum) which are possessed by space equipment, are very valuable for various branches of industry on Earth. Moreover, if the cost of this equipment is greatly reduced, then its widespread use in industry will become an actuality. Certain steps in this direction have already been undertaken. For example, in those instances in which the use of such relatively expensive devices is economically advisable (in radio-electronic and other branches of industry) the devices developed by the Institute are being operated successfully.

Thus our basic goal — the maximum utilization of the achievements of space engineering and technology to enhance the welfare of mankind on Earth — is today already being realized.

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